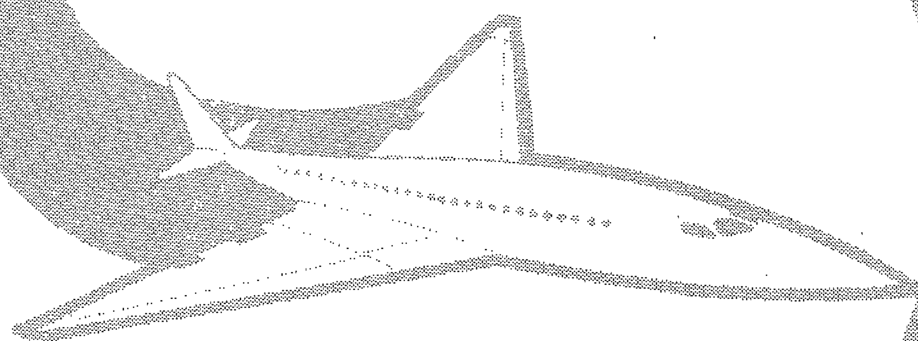
Aircraft Wing Compartment Liner Concept to Reduce Fuel Spillage

Robert F. Salmon



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16. Abstract

This report describes a new concept in aircraft fuel tank design. The concept has the potential for reducing the spillage from an aircraft fuel tank which has been ruptured during what could be considered a survivable crash. The time element is very critical for survival after a crash. By reducing the amount of fuel spilled during the first minute after the aircraft comes to rest, the probability of passenger survival can be greatly enhanced.

The penalties in weight and reduction in fuel capacity resulting from installing the new containment system appear to be minor. The reduction in fuel capacity in a 707 type aircraft, for instance, would be approximately 44 gallons or 0.32 percent of total fuel capacity.

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EXECUTIVE SUMMARY

This report describes an innovative concept for containing fuel in the fuel tanks of aircraft involved in survivable crashes. The concept involves the use of rapid response hydraulic/air actuated closures to seal liners in tank compartments of a fuel tank. With the closures in operation, any fuel spillage can only come from the ruptured compartment or compartments, not from the entire tank. However, in contrast to bladder systems which introduce great complexity to the fuel system, this concept is a passive system which can be installed in a commercial transport aircraft without major modification to the existing fuel system. The weight penalty and reduction in fuel capacity resulting from the installation of such a system appear to be minimal.

A prototype system was built at the Federal Aviation Administration (FAA) Technical Center. Compared to alternate containment systems (i.e., fuel bladders or reticulated foam), this concept incurs lower weight and volume penalties. Installation costs for retrofitting existing aircraft are expected to be significantly less than those incurred when using either reticulated foam or fuel bladders. This savings would result from the fact that no functional changes to the fuel system are required when this system is added to the aircraft. If the concept was incorporated in the original design of a new aircraft, the costs could be significantly lower.

INTRODUCTION

PURPOSE.

The purpose of this report is to describe an innovative concept in aircraft fuel tank design which will reduce the spillage from an aircraft fuel tank which has been ruptured during what could be considered a survivable crash. The time element is very critical for survival after a crash. By reducing the amount of fuel spilled during the first minute after the aircraft comes to rest, the probability of passenger survival is greatly enhanced. The report is divided into four sections:

- Description of a full-scale fuel tank section which was modified to incorporate the components of the new concept.

- Brief discussion of the potential for incorporating the concept into present day commercial carriers.

- Comparison of the new concept's performance penalties relative to the penalties incurred when using either reticulated foam or bladder tanks in aircraft.

- Discussion of the technical viability of the concept.

BACKGROUND.

Fuel fires are the major cause of fatalities in impact-survivable aircraft accidents. Fuel flowing from ruptured fuel tanks while the aircraft is still moving can form fine, readily ignitable mists. The remaining fuel, which spills from the tank after the plane comes to a stop, also constitutes a major potential fire hazard. Dealing with the spilled fuel is the subject of this effort.

The Federal Aviation Administration (FAA) and other government agencies have conducted a significant amount of work on developing methods of containing fuel during accidents. Most of this past work, however, is not applicable to modern, commercial transports owing to excessive weight, cost, or range/capacity penalties.

DISCUSSION

A report (reference 1) was published in 1987 which summarized the various concepts that have been considered for reducing the severity of postcrash fires. The title of the report is "Fuel Containment Concepts - Transport Category Airplanes." After analyzing the various concepts presented, a new concept was developed which appears to minimize the penalties of weight and aircraft performance and yet offers considerable promise in reducing the size of postcrash fires. The essence of the new concept is to apply the principles employed aboard a ship when the integrity of the ship's hull is threatened. Aboard a Naval ship, when an accident occurs or enemy action causes damage, the various compartments of the ship are sealed off to isolate the damage. Thus, the idea is to keep the sea out of the compartments which are still intact and minimize and isolate the impact of the damage. The same concept can be applied to an aircraft's fuel tanks.

Fire is the major contributor to fatalities when an otherwise survivable aircraft crash occurs. There are two major factors in this type of situation which are the prime causes of the fatalities. One is the development of a fuel mist which occurs while the aircraft is still moving and fuel is released from a rupture in the fuel tank. The second factor is the fuel spilled from the ruptured fuel tank which results in a sizable pool of fuel on the ground under the aircraft when it comes to rest. This pool, if exposed to an ignition source can develop into a very large fire encompassing the aircraft. Thus, there are two problems to be solved: one, reduce or eliminate the fuel mist fireball; and two, minimize the size of the fuel spill and the potential fire size. Antimisting fuel (reference 2) can address the misting and fireball problem. The fuel spillage problem is the subject discussed in this report.

Over the years, a great deal of work has been done on methods (reference 1) to contain the fuel in a crash. Most of this work dealt with structural design of the wing and fuel tanks, frangible fittings for the fuel system, installation of bladders in the tanks to improve the containment of the fuel, and use of reticulated foam to impede the spill rate of the fuel. Some of the modifications have been implemented in specialized aircraft. For instance, helicopters have been using bladders and frangible fittings for about 15 years and have found that they perform quite well. However, most of the containment proposals over the years are not readily adaptable to typical commercial transport aircraft. The modifications required would be prohibitive in weight, cost, or reduction in fuel capacity, thus reducing the maximum range of the aircraft.

This report describes a containment concept which would not penalize the aircraft performance to any significant extent and would not compromise existing fuel systems.

DESCRIPTION OF A FUEL CONTAINMENT SYSTEM

Many studies over the years have defined the causative factors which influence the potential for fatalities in aircraft accidents. Obviously high velocity crashes into obstructions such as trees or mountains are almost always fatal. However, when impact survivable crashes occur there are generally many fatalities which can be attributed to fire. These deaths may result from fire directly or the fumes produced by a fire. The fires result from the release of fuel which takes place when the fuel system or the fuel tanks are damaged and large quantities of fuel are spilled in the vicinity of the fuselage. At the same time that fuel is released, potential ignition sources are also produced. The accident data indicate that the survivability rate of moderate aircraft accidents is related to the degree of success of the aircraft in containing its fuel. If there is a large release of fuel and a large spillage area when the aircraft comes to rest, the survivable rate for passengers is greatly reduced. The following section describes a method of improving the fuel containment capabilities of transport aircraft.

A typical wet wing of a commercial transport airplane consists of an inboard tank and an outboard tank. The tank has baffle bulkheads to minimize sloshing. For instance an outboard tank might be 15 feet long, have a height from 12 inches at the inboard end to 8 inches at the outboard end, and have a chord of 6 feet at the inboard end and 4 feet at the outboard end. This is shown schematically in figure 1 below.

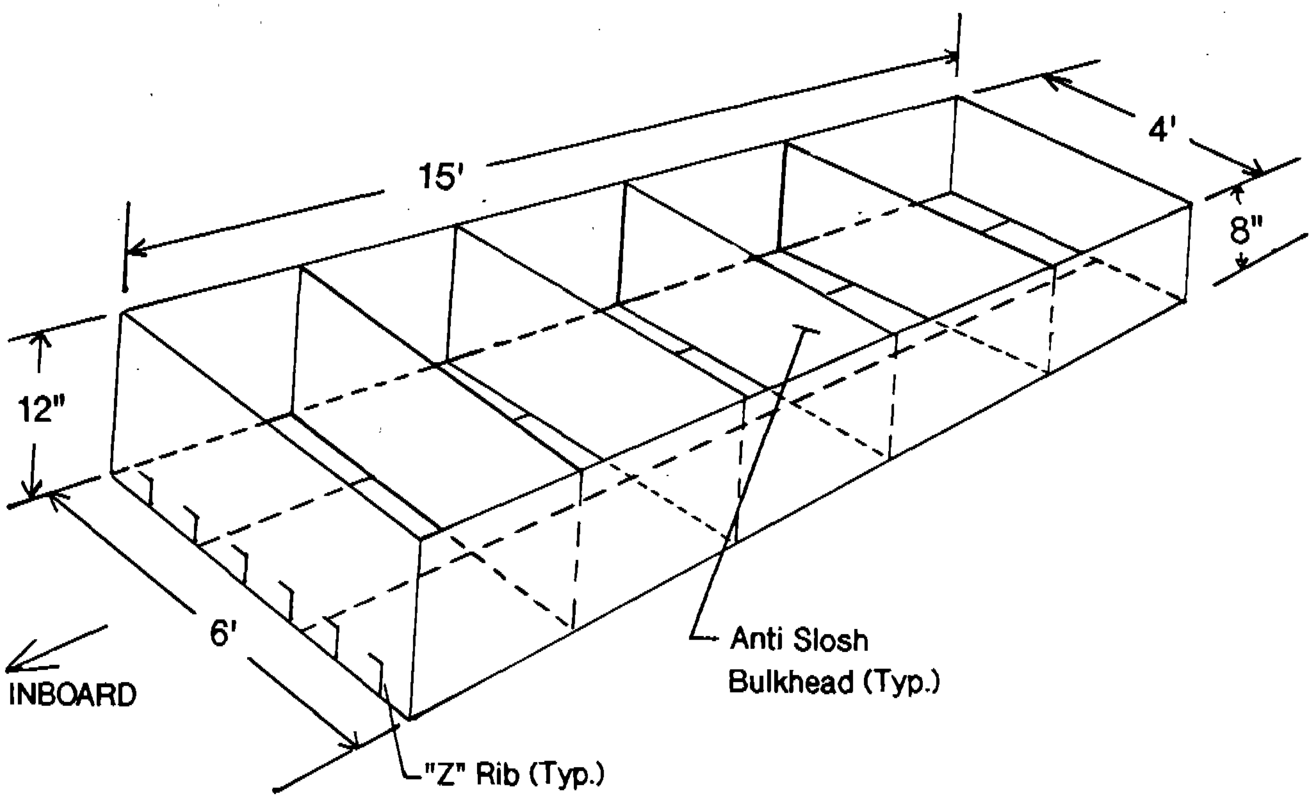

FIGURE 1. OUTBOARD WING TANK

To provide strength to the wing, the upper and lower skin is reinforced, usually with "Z" sections, spaced chordwise about 7 inches apart. Figure 2 shows the general configuration of the wing stiffeners. The Z sections run spanwise in the tank and the antislosh bulkheads are attached to the sections at the upper and lower wing skin.

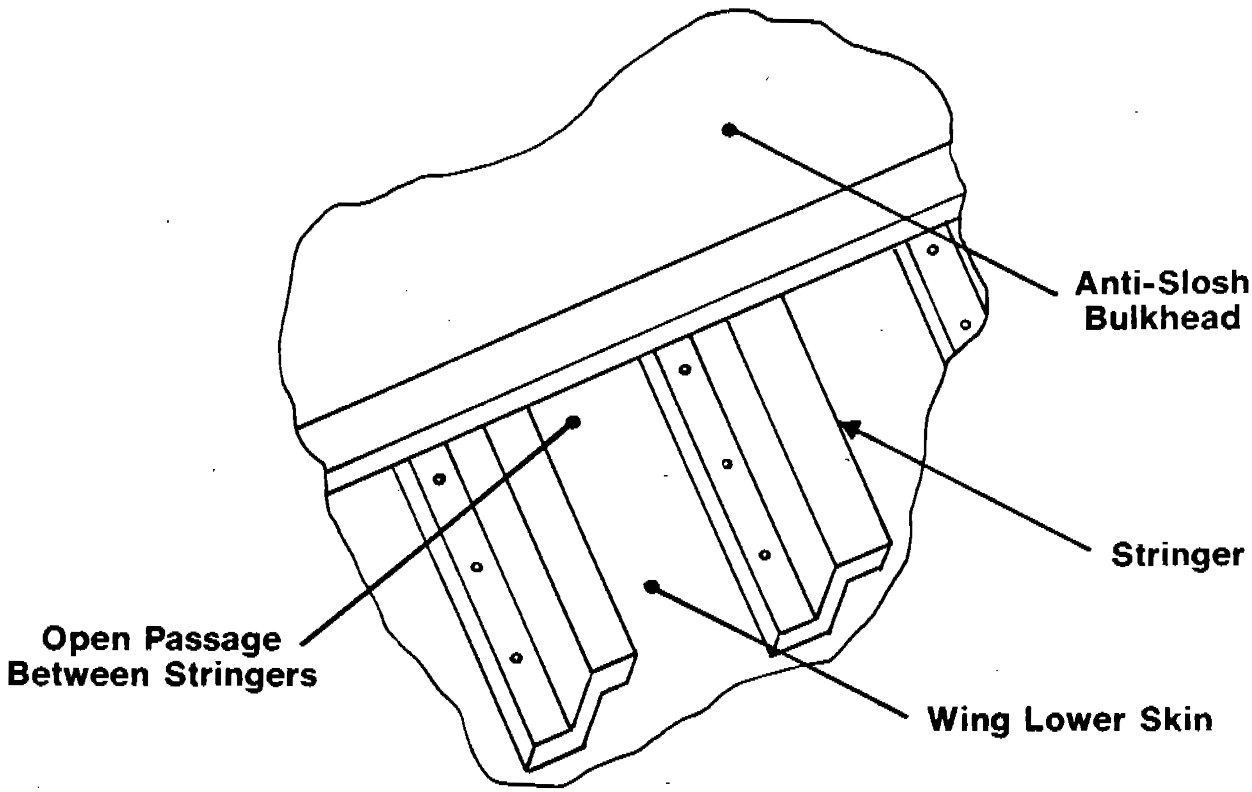

FIGURE 2. "Z" RIBS

This results in compartments which are shown in figure 3. The baffle (or antislosh bulkhead) is raised above the wing skin thus permitting fuel to flow freely from compartment to compartment between the "Z" sections. The height of the Z section is about 2.5 inches. However, in order not to starve an engine when the tank is almost empty, a means is provided for the fuel to flow freely between rib channels. Without such a provision the lowest 2.5 inches of fuel in the tank would be unusable. The method used to permit fuel to flow from rib channel to channel is relatively simple. At the inboard end of the wing tank the Z sections are tapered down from a height of 2.5 inches to about 0.75 inches.

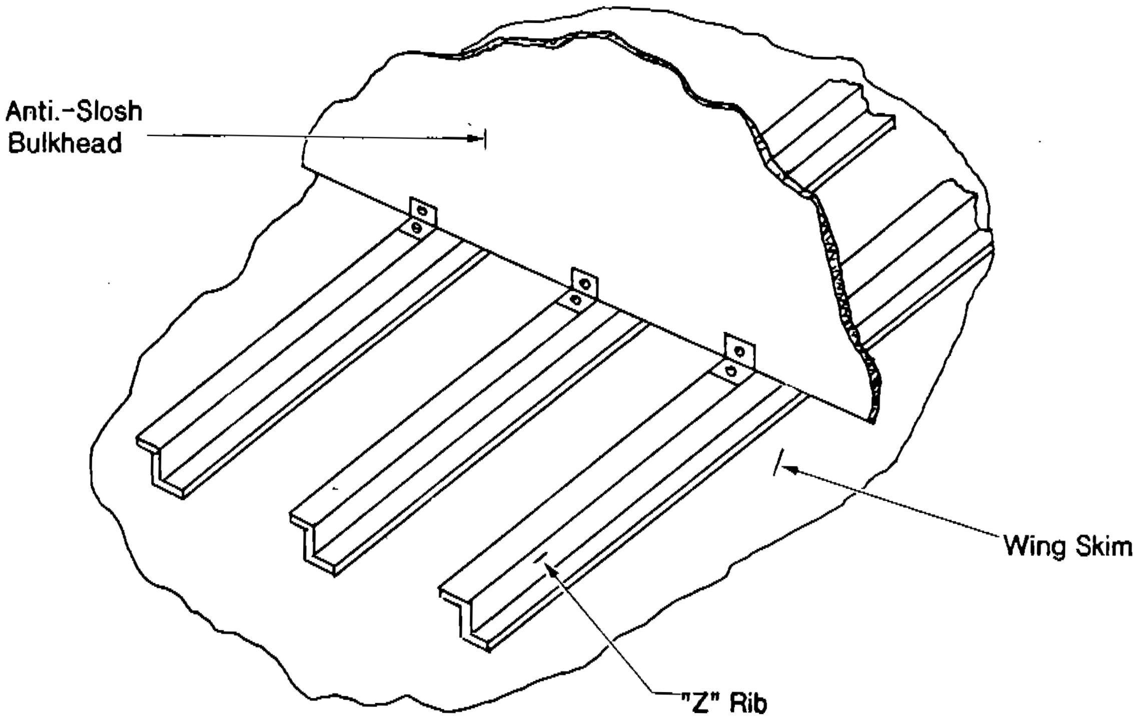

FIGURE 3. ANTI-SLOSH BULKHEAD

This permits the fuel to drain from channel to channel to within 0.75 inches of the bottom of the tank. When the fuel level is very low in the tank, the wing in flight has a greater upward deflection and the outboard section of the tank drains inboard to this low point, and practically all the fuel is usable. Figure 4 illustrates this point. It should be noted that small passages (approximately 1/16th inch in diameter) are provided in the ribs to permit flow from channel to channel in order to actually drain a tank completely. The total unusable fuel in a tank is very small. The tapered Z rib at the inboard end provides a sufficient passage to assure that no sizeable quantity of fuel is unusable. This is the general design of a typical wing fuel tank.

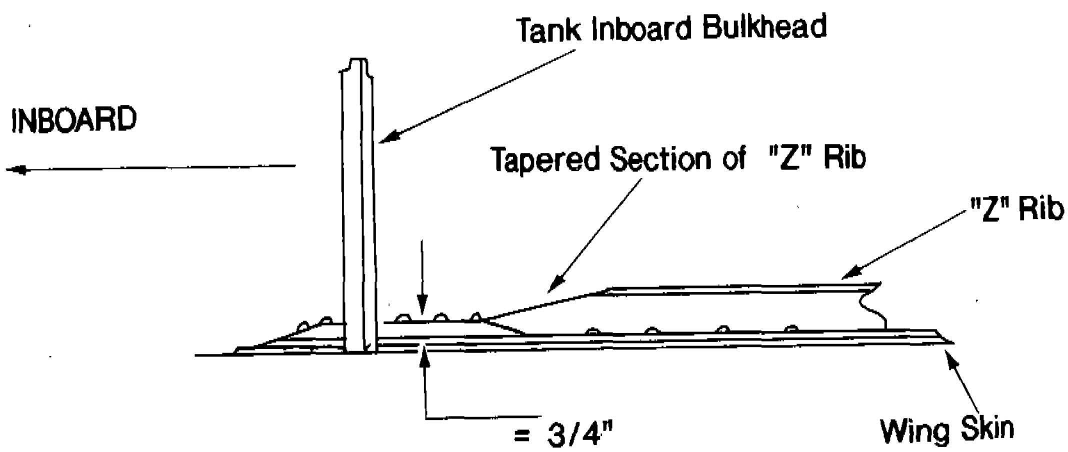

FIGURE 4. TAPERED SECTION OF "Z" RIB

PROTOTYPE FUEL CONTAINMENT SYSTEM

The purpose of this system is to isolate the effects of a wing tank rupture. If the typical in-service wing tank presently used is damaged, all of the fuel in the tank will be spilled. There is no mechanism to minimize the spill when the tank's integrity is compromised. The fuel containment system described herein will overcome that deficiency in wing tank design with only minimum compromising of the aircraft's fuel capacity or existing fuel system design. The system consists of several components: a lightweight flexible open top liner, a lightweight frame to support the liner, a two position valve (full open or full closed) incorporated in each liner, and extensions on the Z ribs at the inboard end of the tank. Each such extension has a two-position valve incorporated in the extension. The modifications to the tank which will incorporate the containment system are described below. In order to clarify the description, an example of the system will be applied to an outboard wing tank as shown in figure 1.

COMPARTMENT LINER CONCEPT APPLIED TO AN OUTBOARD WING TANK.

A lightweight frame will be installed in each compartment. This frame will be designed so it can be installed and assembled through the access ports provided in the wing. A typical frame for the tank described in figure 1 could be as shown in figure 5.

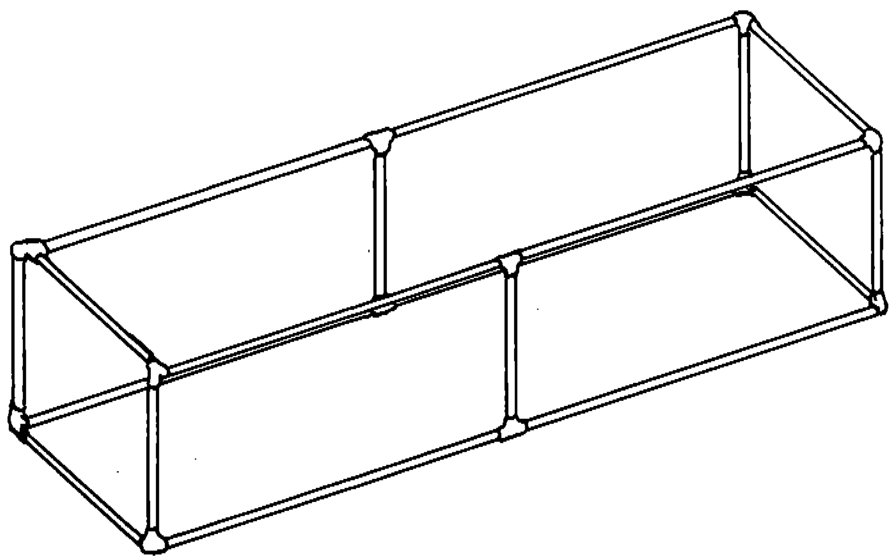

FIGURE 5. COMPARTMENT FRAME ASSEMBLY

When the frame is installed and fitted in the compartment, a lightweight tear resistant liner is installed inside the frame. The liner is shown in figure 6.

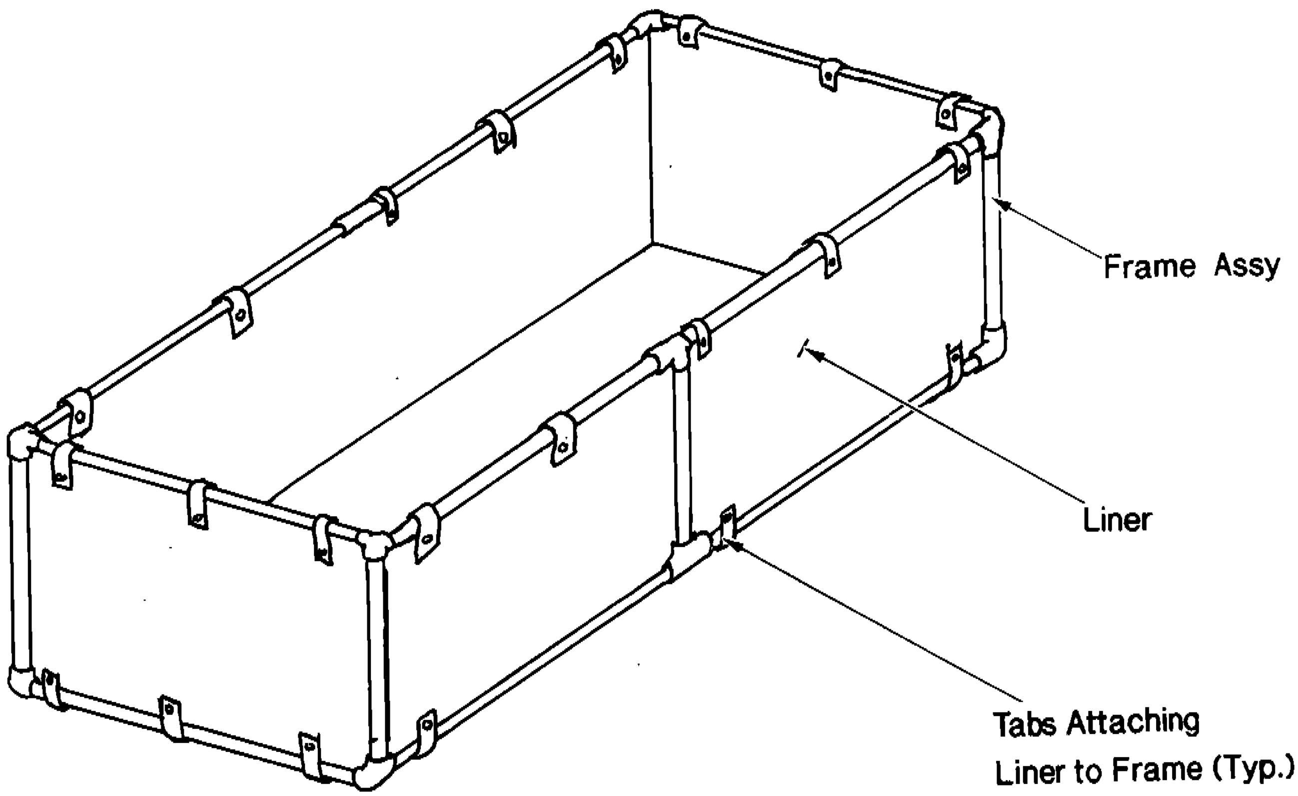

FIGURE 6. OPEN TOP COMPARTMENT LINER

The liner is an open top component that is attached to the support frame by tabs. A two-position valve is installed in the liner base. The valve is normally open over a 4-inch-diameter passage but can seal the 4-inch opening on command. The valve is shown in figure 7. The weight of the actuator and valve is about 1.5 pounds. The valve is assembled integral with the liner prior to installation in the wing compartment.

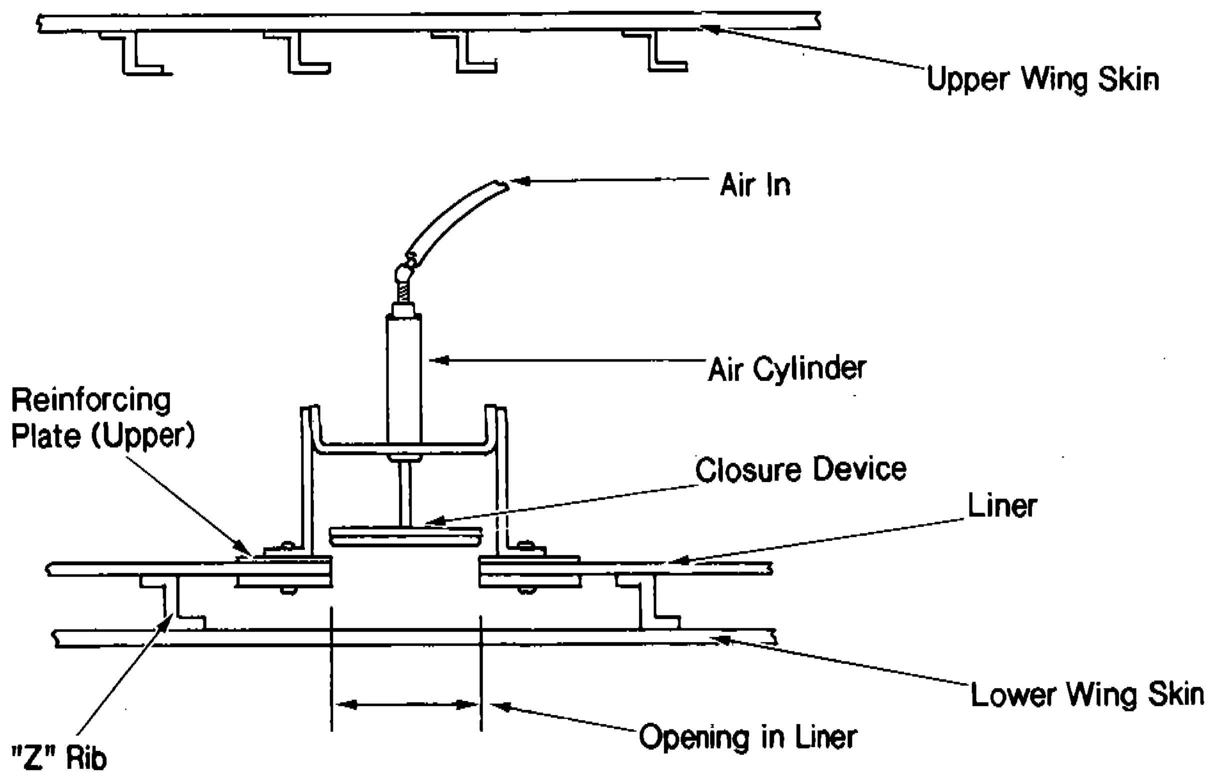

FIGURE 7. VALVE IN COMPARTMENT LINER

The other major component of the system is the device designed to prevent interchannel flow after the fuel level is below the height of the Z ribs. It was pointed out earlier that the Z ribs taper down at the inboard end of the tank to permit interchannel flow. The method for closing off the interchannel flow is shown in figures 8 and 9.

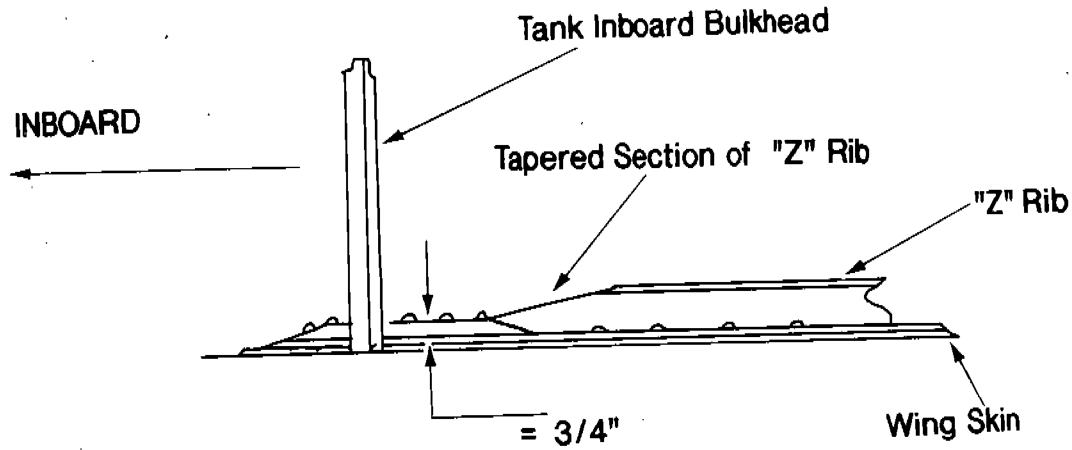

FIGURE 8. "Z" RIB TAPERED SECTION

To close off the tapered section, a formed piece which includes a two-position valve is attached to the Z rib and the inboard wall of the tank. This piece is shown in figure 9.

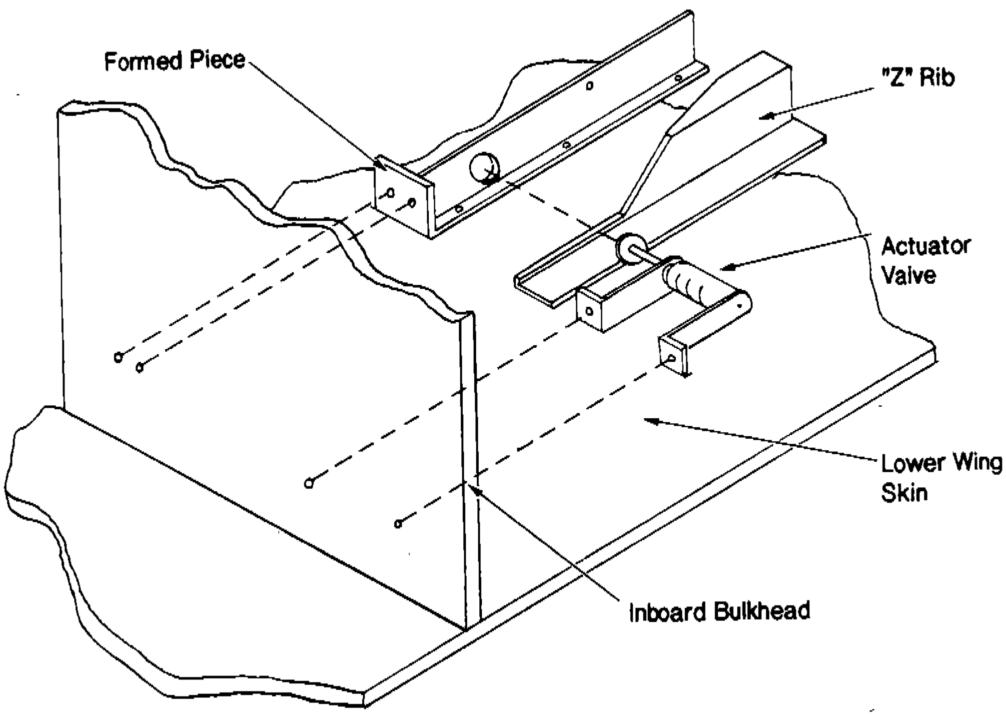

FIGURE 9. MODIFICATION TO "Z" RIB

The formed piece (figure 9) is installed on every other Z rib in the tank. This device permits fuel to flow from channel to channel through a 1.5-inch hole under all normal operating conditions. When the valve is closed during an emergency, the fuel in the channels will not have an interchannel flow when the fuel level in the tank is no higher than the Z rib.

The installed system is best understood by referring to figure 10. The figure shows the installation of the components which would be installed in one compartment of a tank.

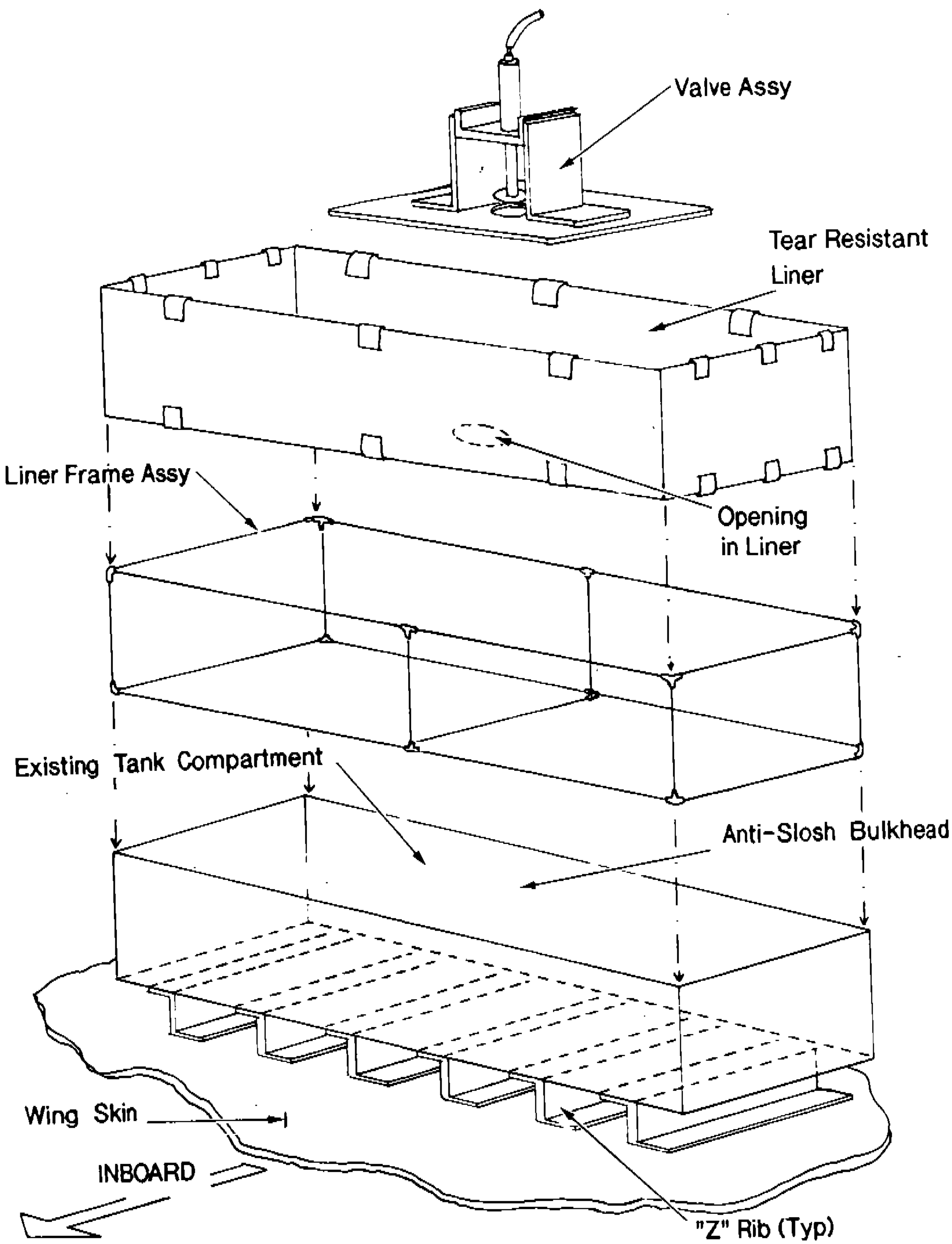

FIGURE 10. EXPLODED VIEW OF CONTAINMENT DESIGN

It should be noted that the liner is a passive membrane. It does not have to withstand hydraulic shock or impact pressures since it is surrounded by fuel during normal operation. The only time there is any moderate load on the liner is when the closures are actuated and, due to wing skin rupture, the fuel outside the liner is drained. At that time, the frame supports the walls of the liner, and the bottom of the liner is supported by the Z ribs on the lower wing skin. At that time, the aircraft should be at rest.

In order to better understand the operation of the system, an example of a survivable crash wherein the fuel tank is penetrated is presented.

Assume the fuel tank described in figure 1 is partially full. Even though total capacity of the tank is 467 gallons, it actually contains 374 gallons at the time of the crash. The height of the fuel in the liner is 5.5 inches, i.e., overall height of the fuel in the tank (8 inches minus the fuel between the Z ribs, 2.5 inches). Therefore the fuel in one liner compartment is 51.4 gallons. The total fuel in the space between the Z ribs is 117 gallons (the total amount of fuel in the entire outboard tank between the Z ribs). With the closure devices on the Z ribs actuated, interchannel flow between the Z ribs is blocked. The amount of fuel between any three ribs running the length of the tank is approximately 27.3 gallons. The total amount of fuel which is outside the liner between the tank walls and the liner above the Z ribs is approximately 8.6 gallons.

Assume that during the crash a 10-inch-diameter hole is torn in the wing and this rupture also penetrates the liner in one compartment. The containment system is operated. The closures on the Z ribs and the closures in each of the liners are operated.

The total spillage in this instance will come from the ruptured liner, the fuel outside the liners above the Z ribs, and two channels of fuel in the space below the height of the Z rib (see figure 11). This summation is:

Liner spillage	51.4 gallons
Fuel outside the liner	8.6 gallons
Fuel between the ribs	27.3 gallons
Total	87.3 gallons

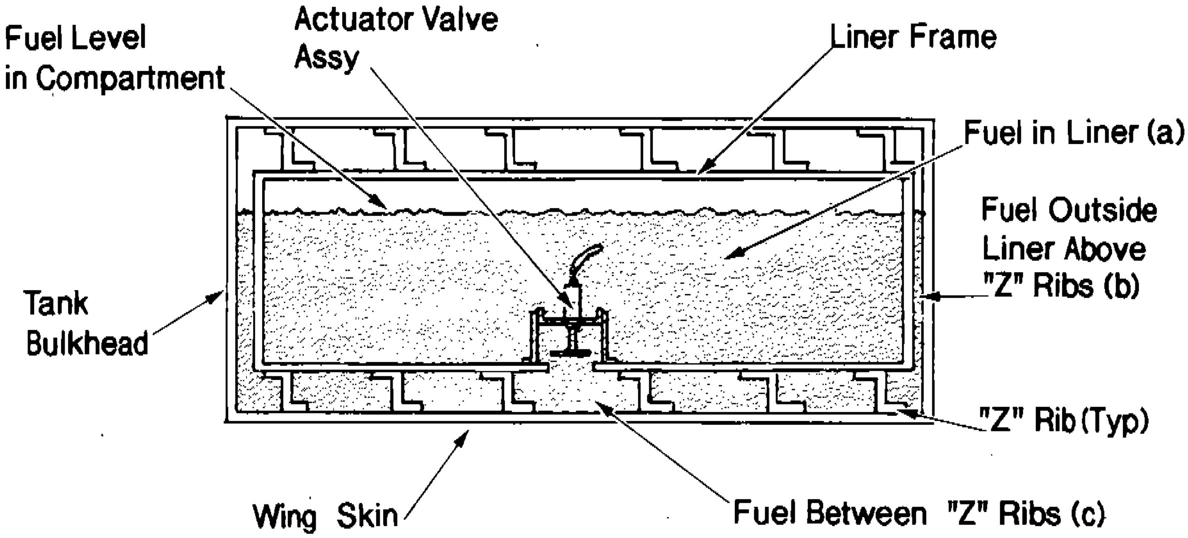

FIGURE 11. CROSS-SECTION OF COMPARTMENT WITH FUEL

With the total height of the fuel in the tank at 8 inches, the flow rate of the spillage through the 10-inch-diameter hole varies from 23.1 gallons per second (gal/s), initially, to 3.0 gal/s for the last half-inch of head pressure. The elapsed time for complete spillage would be 7.3 seconds. If the run-out time from impact until the aircraft comes to rest is assumed to be 9 seconds, there should be no spillage pool except for some dripping from the "wetted" wing surface.

When an unmodified tank is ruptured in a similar manner as the modified tank, the range of spillage rates is the same (i.e., 23.1 to 3.0 gal/s), but the duration of the spillage is much longer. At the instant of rupture there would be 374 gallons in the tank; all of which would be subject to spillage. In the first 9 seconds (the run-out time), 184 gallons would be spilled leaving 190 gallons in the tank when it comes to rest (see figure 12). At the end of 31 seconds, 15 gallons still remain in the tank subject to spillage. A spillage of 190 gallons (assuming 1/16th of an inch pool depth) would result in a spillage pool 79.8 feet in diameter. A pool of this magnitude would engulf the aircraft.

A more severe example would be when the rupture of the tank damages two compartments, two liners, and two sets of interchannel ribs. The total fuel that would spill in such an instance would be:

Two-liner spillage	102.8 gallons
Fuel outside the liners	8.6 gallons
Fuel between two interchannel sections	54.6 gallons
Total	166.0 gallons

With the total height of the fuel in the tank at 8 inches, the flow rate of the spillage varies through the 10-inch-diameter hole from 23.1 to 3.0 gal/s for the last half-inch of head pressure. The elapsed time for the complete spillage would be 14.3 seconds. The amount of fuel in the tank after a 9-second run-out would be 21 gallons, and a pool resulting from this spillage would be 26.2 feet in diameter.

Figure 12 illustrates the performance of the containment system when applied to an outboard wing tank.

The examples cited above are for situations when an outboard wing tank ruptured. An incident where the inboard wing tank is similarly ruptured would show that the fuel containment system would be even more effective in retaining most of the fuel.

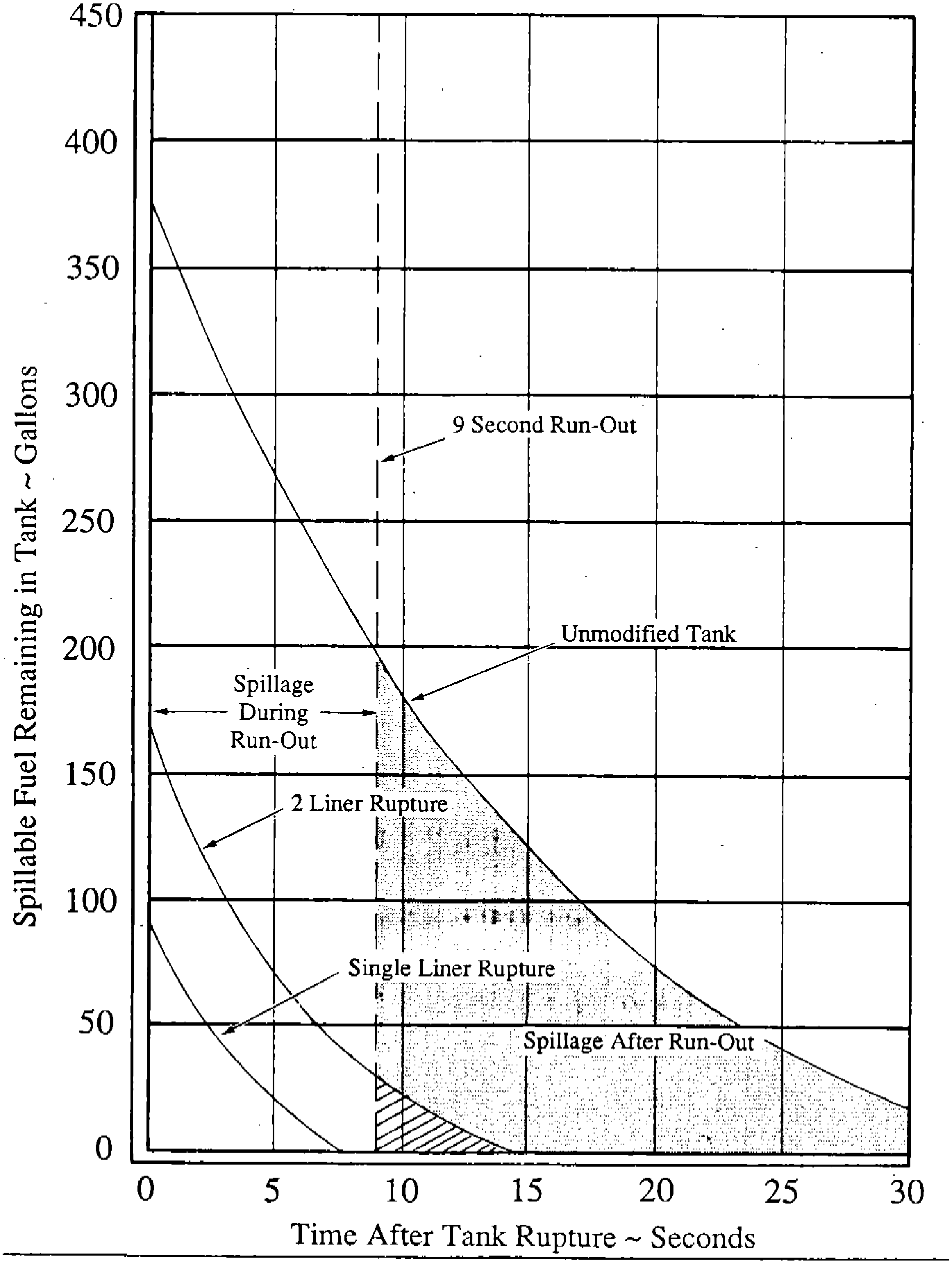

FIGURE 12. OUTBOARD WING TANK SPILLAGE VERSUS TIME

COMPARTMENT LINER CONCEPT APPLIED TO INBOARD WING TANKS.

In the case where an inboard wing tank is ruptured during an accident, a large pool spillage is very probable. A tank near the wing root could contain as much as 3600 gallons of fuel. A spillage of this size in the immediate vicinity of the aircraft fuselage would be devastating. If the tank in the wing root section were to be modified to incorporate the containment system outlined in this report, it would have additional features. To understand the features refer to figure 13.

In figure 13, the inboard wing tank (No. 3 tank) has a capacity of 3646 gallons distributed in five compartments. At the time of the accident, the tank is 70 percent full (i.e, 2552 gallons). The accident causes a 10-inch-diameter break in the tank. The height of the fuel in the tank is 21 inches. An unmodified tank would spill 382 gallons during the 9-second run-out, and the balance of the fuel (2170 gallons) would spill in the next 2 minutes. The pool created from this spillage would be 266 feet in diameter (assuming a 1/16th-inch depth of fuel).

The modified tank using a compartment liner would reduce this spillage. The compartment liner would have these average dimensions: 13-foot chord, 2.5-foot height, and 3-foot spanwise width as shown in figure 13.

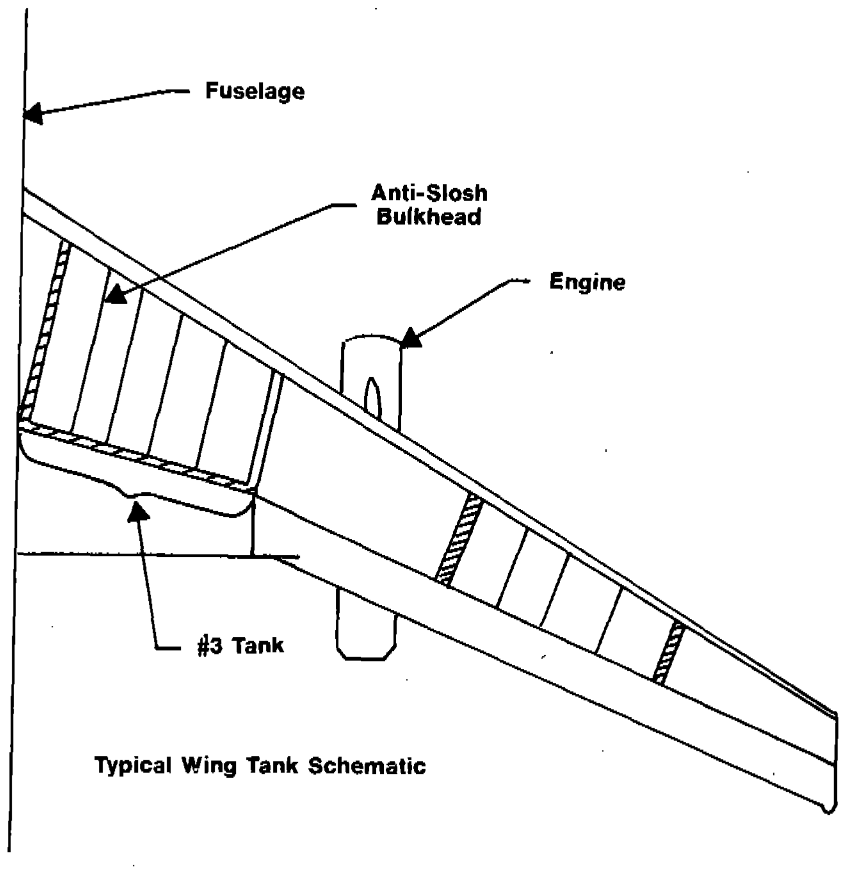

FIGURE 13. SCHEMATIC OF WING AND FUEL TANKS

With the same initial quantity of fuel in the tank (2552 gallons), the compartment would contain 510 gallons (2552 ÷ 5). The summation of spillable fuel in the liner, above the Z ribs and outside the liner, and between three Z ribs below the liner is:

Fuel in liner	434.55 gallons
Fuel outside liner above "Z" ribs	27.3 gallons
Fuel between "Z" ribs	77.0 gallons
Total	538.85 gallons

In the first 9 seconds, a total of 279 gallons would spill, and 260 gallons would be the spillage volume of the pool when the aircraft comes to rest. This spillage would be almost complete in 27.6 seconds. A spillage pool with a 92-foot diameter would result in this case. An analysis of accident data wherein the inboard wing tank has been ruptured indicates that the leading edge and the forward part of the tank incur the damage in the majority of such incidents. Therefore, the subcompartmenting of the liner as shown in figure 14 is suggested.

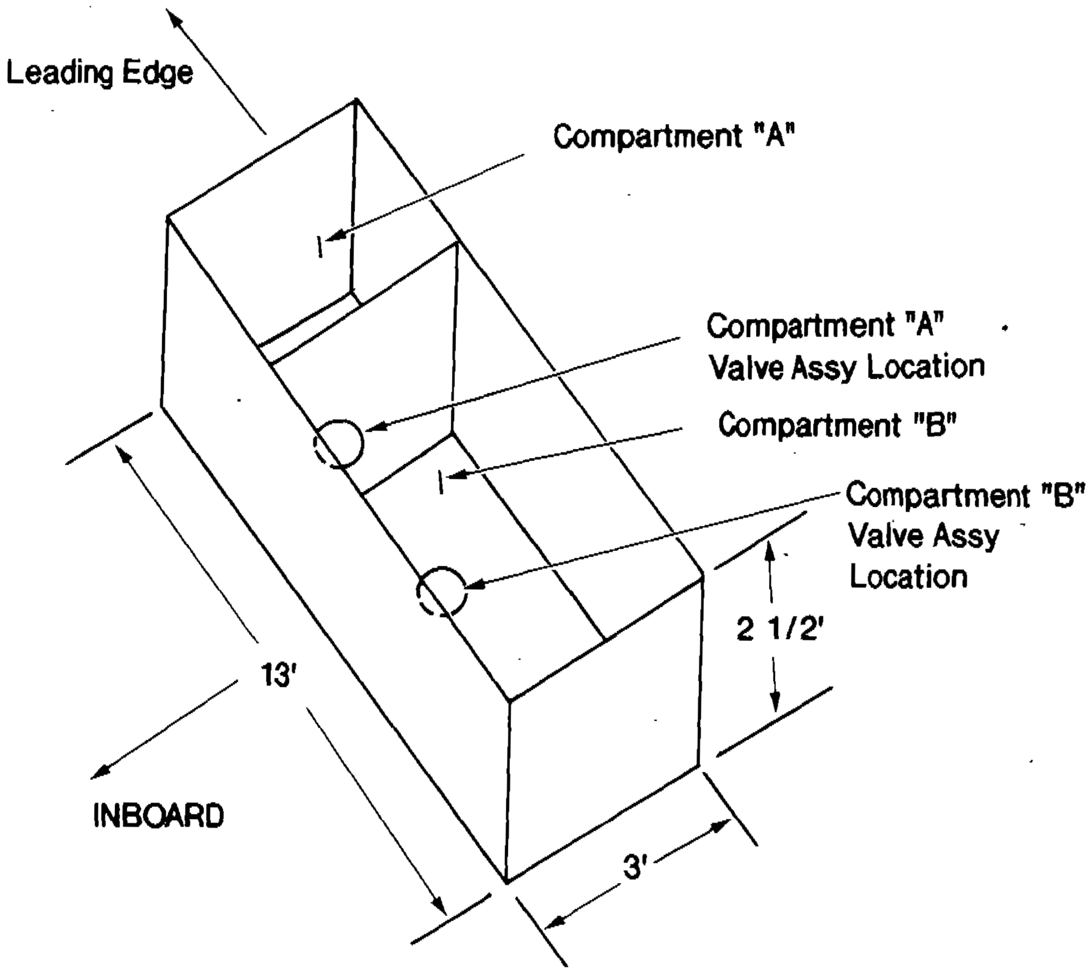

FIGURE 14. INBOARD WING TANK LINER SCHEMATIC

If the liners for the inboard tank have two compartments, as shown in figure 14, and compartment A contained one-quarter of the spillable fuel in the liner, the total potential spillage would be 163.92 gallons with an initial 21-inch head pressure in the tank, the total quantity of spillable fuel would be spilled in approximately 8 seconds. Figure 15 compares the performance of the three tank configurations.

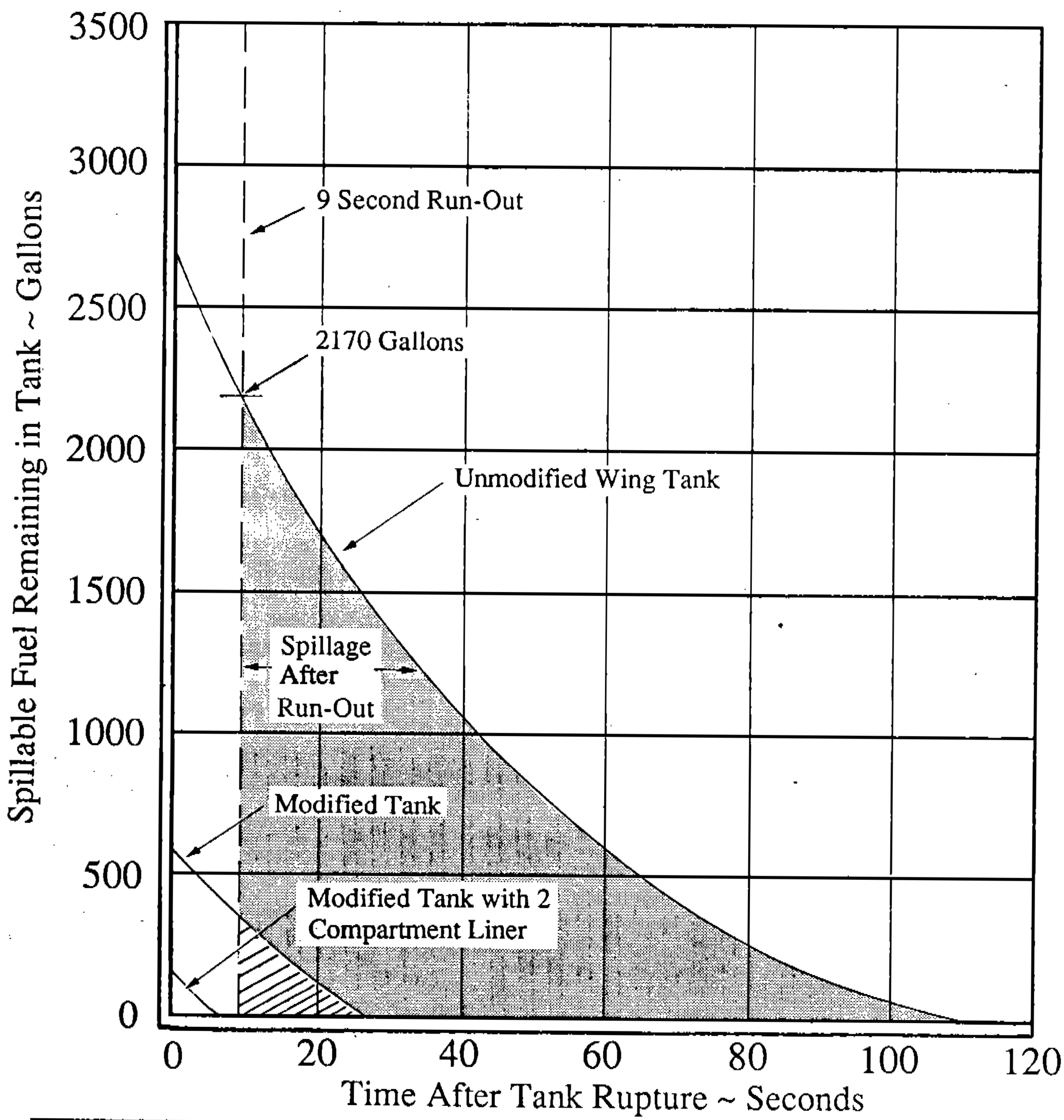

FIGURE 15. INBOARD WING TANK SPILLAGE VERSUS TIME

The design for inboard wing tank liners would be different from the outboard tank liners in some ways. The outboard tanks have less height than inboard tanks and have access ports in each compartment of the tank. There is no provision for intercompartment access for repairs because of the limited height of the tank. For this reason some type of frame is required in order to support the liner. This was discussed earlier in this report.

The inboard tanks, however, can incorporate the containment system without using a frame. Each compartment can be accessed by a mechanic through the openings in the anti-slosh bulkheads. With one tank access port on the lower surface of the wing, a mechanic can enter the tank and install a liner in each compartment. The mechanic can install ring hangers on every other Z rib on the upper and lower wing skin, and the liners can be snapped on the rings. This would simplify the installation, removal, and inspection of the tank and also reduce the overall weight penalty for a complete aircraft installation of the system. Figure 16 illustrates this feature.

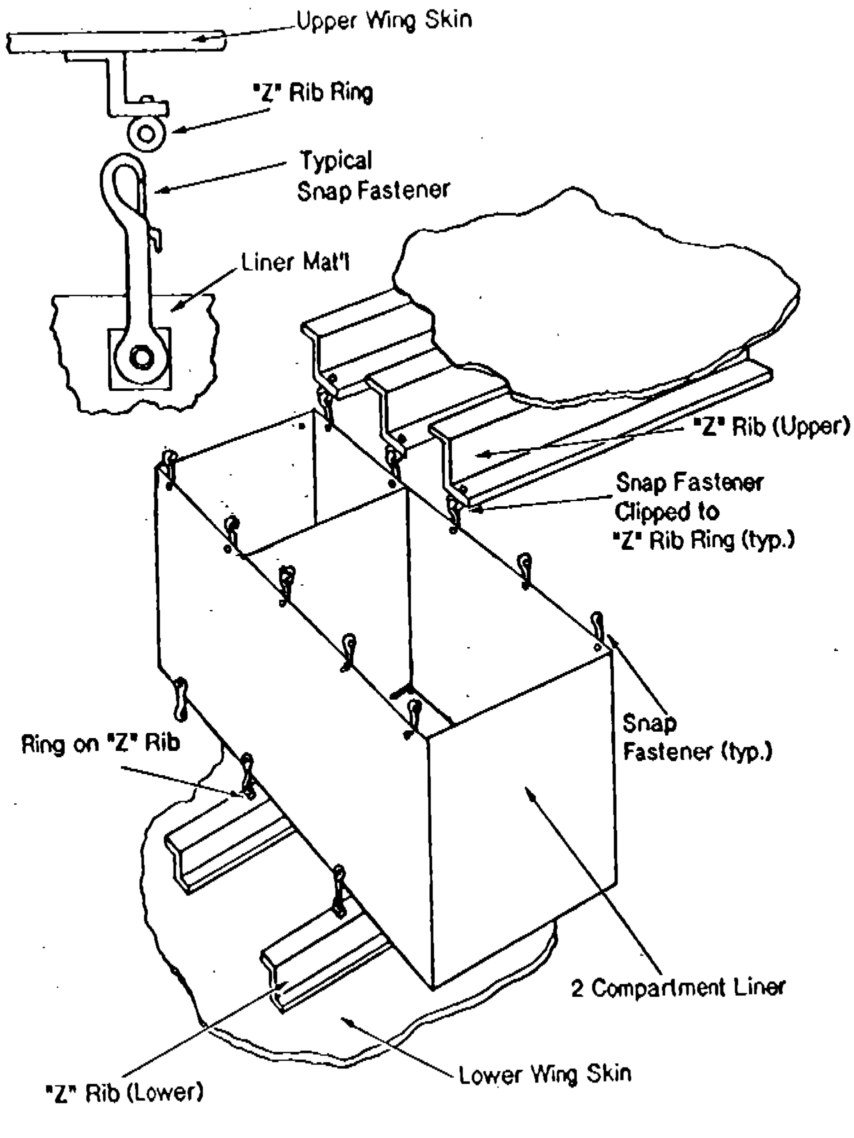

FIGURE 16. INBOARD WING TANK LINER INSTALLATION

CONTAINMENT SYSTEM WEIGHT AND VOLUME COMPARISONS FOR BLADDERS, FOAM, AND NEW CONCEPT

A comparison of the approaches usually considered when addressing the containment problem proves to be very pertinent. The methods which are usually advanced are crash resistant fuel cells (bladders) and reticulated foam. In order to compare these systems, the aircraft wing design shown in figure 13 is used as the basis for comparison.

BLADDERS.

With bladders which would be installed in the five compartments of tank number 3, the total surface area of the bladders is 790 square feet (ft^2). Tank number 2 also uses 790 ft^2 and tanks number 1 and 4 would use 70 percent of this figure. The total surface area of the bladders would be 2586 ft^2. The typical weight of the bladder material is 1.5 pounds/ft^2 (appendix A) and total weight therefore would be 3879 pounds.

The displaced volume when using the bladders is:

$(2586 \times 0.1875 \times 1/12) + (13 \times 15 \times 0.4167)2 + (13 \times 15 \times 0.4167)2(0.7) =$ 316.6 ft^3. This volume reduces the aircraft fuel capacity by 2639 gallons, equivalent to a 19.1 percent fuel capacity reduction.

FOAM.

The reticulated foam has a density of approximately 1.5 pounds/ft^3 (appendix B). The total volume of tanks number 1 through 4 is 1657 ft^3 (or 13,818 gallons). The weight of the foam therefore is 1486 pounds.

The foam displaces 2.5 percent of the tank volume, and the foam also retains 2.5 percent of the fuel. The useful volume penalty when using foam is: $(0.05)\ 1657 = 82.85$ ft^3 or 690 gallons.

NEW CONCEPT.

The system as installed in a test section of a 707 wing provides a basis for estimating the total weight and range penalty for a complete aircraft.

1. There would be five liners installed in the five compartments of tank number 3. The total area of the liners would be 515 ft^2. The fabric for the liners would weigh approximately 0.12 lbs/ft^2, and the weight of the liner material would be 61.8 lbs. This would be the same for the number 2 tank. For numbers 1 and 4 the weight would be 70 percent of this. The overall weight for liner material would be 210 lbs.

2. The weight of the frames based on using 1/4-inch aluminum tubing with a 1/16-inch wall thickness would be 3.1 lbs for each compartment in number 3 tank. Number 2 would use the same amount of framing, and numbers 1 and 4 would use 70 percent of this. The overall weight of framing per aircraft would be 51.6 lbs.

3. The weight of the valve assemblies would be:

   a. Interchannel valve assemblies (10 each per tank) at 1-1/2 lbs per assembly = 15 lbs/tank. For four tanks the weight would be 60 lbs.

   b. Five valve assemblies per tank and four tanks or 20 valve assemblies at 1-1/2 lbs/assembly = 30 lbs.

   c. Overall weight of valve assemblies would be 90 lbs.

4. The weight of tubing, brackets, controls, etc., per aircraft would be approximately 30 lbs.

5. The overall weight of the system for an aircraft would be approximately 383 lbs.

The fuel displaced by the system would result from the volume of the fabric liner, the valve assemblies, the liner frames, and incidental hardware, i.e., tubing, brackets, etc. The breakdown would be as follows:

Liners	35.00 gallons
Frames	2.34 gallons
Valve Assemblies	1.05 gallons
Incid. Hardware	5.00 gallons
Total	43.39 or 44 gallons

It should be noted that no serious attempt at minimizing the weight of the system has been made at this point.

The summary of the characteristics and performance of the three types of containment concepts is shown in table 1.

TABLE 1. COMPARISON OF THREE CONTAINMENT CONCEPTS

Concept	Displaced Volume	Weight of System	Calculated Reduction in Fuel Capacity
Bladders	316.6 ft^3	3879 lbs.	2369 gallons (19.1% reduction)
Foam	82.85 ft^3	2486 lbs.	690 gallons (5% reduction)
New System	5.88 ft^3	383 lbs.	44 gallons (0.32% reduction)

SIGNIFICANT FEATURES OF THE CONTAINMENT SYSTEM

The analysis of tests conducted to evaluate the new containment system concept indicates that it is very effective in reducing the pool spillage area when a damaged aircraft comes to rest. This, however, is only one facet of the containment problem. The other major considerations are:

1. Is the system compatible with the existing aircraft fuel system?
2. What would be the consequences of inadvertent actuation of the system?
3. Can the system be checked to assure that it is operational?
4. What approach should be used to optimize the operational procedure?

COMPATIBILITY WITH EXISTING FUEL SYSTEM.

Since the components of the system are aluminum, steel, fabric liner, and tubing, all of which would be compatible with Jet A fuel, there should be no problems with compatibility.

The existing fuel system is not impacted by installing the system since it is a passive concept and is only operated on demand. Some minor rerouting of plumbing would take place in order to install the liners. There would be no necessity to modify the basic fuel system design.

ACTUATION OF THE SYSTEM.

If the system is actuated and the various liners are sealed off due to inadvertent action, a warning light could alert the pilot and the system could be returned to normal in a fraction of a second. An inadvertent actuation would not starve the engines because there is sufficient fuel between the tank liners and the tank walls and between the Z ribs to supply the engines for several minutes.

CHECK-OUT OF THE SYSTEM.

The system could be checked before takeoff or at any time by actuating the various closure devices in the compartments. It is not essential that each liner be perfectly sealed in order to be effective. Each closure would be capable of sealing off at least 99 percent of the potential flow through any opening. This would greatly reduce the spillage rate. The system can be designed for easy removal for inspection purposes.

OPERATIONAL PROCEDURE.

The actual operating procedure to be used with the containment system described in this report is not defined at this time. This is because the users of the system would have to evaluate the various potential operational procedures. It might be advantageous to have the system actuated only in an emergency situation (for instance, when a wheels-up landing is imminent), or it might be desirable to actuate the system during all takeoffs and landings. There are advantages and disadvantages for each method, but the system's use is best left to a more detailed analysis for specific aircraft types and an evaluation by experts in flight operations. The system must be fail-safe in the open position. If for some reason the air or hydraulic pressure to the actuators is lost, the spring-loaded actuators would hold the closure devices in the open position.

The essential features of the containment concept are outlined here, but the detail design of the installation and controls would be developed through extensive study and analysis.

REFERENCES

1. Wittlin, G., Fuel Containment Concepts - Transport Category Airplanes, Lockheed-California Company, FAA Report No. DOT/FAA/CT-87/18, November 1987.

2. Yaffee, M., Antimisting Fuel Research and Development for Commercial Aircraft - Final Summary Report, FAA Report No. DOT/FAA/CT-86/7, April 1986.

APPENDIX A

EXCERPT FROM REFERENCE 1, CRASH RESISTANT FUEL CELL INSTALLATION WEIGHTS

Total weight for cell installations based on these materials as well as comparable weights for an installation based on two separate tank responses are given in table 3. Also shown is the loss of fuel capacity resulting from the cell installation.

TABLE 3. CRASH RESISTANT FUEL CELL INSTALLATION WEIGHTS

	Based on Single Tank Response		Based on Two Tank Response	
Weight Item	Optimum Cell Material 1.60 lb/ft2	Probable Cell Material 2.55 lb/ft2	Optimum Cell Material 1.20 lb/ft2	Probable Cell Material 1.90 lb/ft2
Cell Material (936 ft2)	1500	2400	1120	1780
*Fitting Weight (3 x present U.S. Rubber fittings	230	250	220	240
Attachments (nuts, bolts etc.)	60	60	60	60
Tank Liner (2 x present thickness + 100% for stiffening & structure	750	750	750	750
Access Doors & Structural Revision	400	400	400	400
TOTAL	2940	3860	2550	3230

*Average Number of Fittings/Cells	=	10 (vent and fuel interconnects, doors, etc.)
Average Number of Fittings/End Cells	=	8 (vent and fuel interconnects, access doors, etc.)
Miscellaneous Fittings, One each Total	=	4 (tank inlet, outlet, capacitant units, etc.)

TOTAL = 116

<u>INSTALLATION FUEL LOSS:</u>

Internal Tank Capacity = 26,100 lbs. - 4015 gal.
Bladder Cell Capacity = 20,670 lbs.
Capacity Loss = 5,430 lbs. - 835 gal.

<u>20.8% reduction</u> in useful fuel capacity

APPENDIX B

SPECIFICATIONS OF SCOTT FOAM DIVISION'S RETICULATED FOAM PRODUCTS

Mil-B-83054-B	COARSE PORE TYPES*			FINE PORT TYPES*	
Property	Type I	Type II	Type IV*	Type III	Type V
Color	Orange	Yellow	Dark Blue	Red	Light Blue
Polyol Type	Polyester	Polyester	Polyester	Polyester	Polyester
Density Range (lb/ft^3)	1.70-2.00	1.20-1.45	1.20-1.45	1.20-1.45	1.20-1.45
Porosity pore size (PP1)	7-15	8-18	8-18	20-30	20-30
Air Pressure Drop (inches of water)	0.190-0.285	0.140-0.230	0.140-230	0.250-0.330	0.250-0.330
Tensile Strength (psi) Min.	15	15	10	15	15
Tensile Strength at 200T elongation (psi) min.	10	10	-	10	-
Constant Deflection compression set (%) max.	30	35	30	35	30
Compression load deflection at 25% deflection (psi) min.	0.40	0.30	0.35	0.30	0.35
65% deflection (psi) min.	0.60	0.50	0.60	0.50	0.60
Fuel displacement (max. Vol. %)	3.0	2.5	2.5	2.5	2.5
Fuel retention (max. Vol. %)	2.5	2.5	2.5	4.5	4.5
Flammability (inches/minute) max.	10	15	15	15	15
Extractable materials (Wt. %) max.	3.0	3.0	3.0	3.0	3.0
Low Temperature Flexibility (-55°F)	NO CRACKING OR BREAKING OF STRANDS				
Entrained solid contamination (Milligrams/ft^3) Max.	11.0	11.0	11.0	11.0	11.0
Steam autoclave exposure (% Tensil Loss) max. type I, II, III 5 Hrs. @ 250°F Type IV & V 3 Hrs. @ 250°F	40	40	-	40	-

* Above sequence of types I, II, IV, III and V facilitates comparison of ester and ether types